SENSITIVITY OF ARMY HELICOPTER
OPERATING AND SUPPORT COSTS TO
CHANGES IN DESIGN AND
LOGISTIC PARAMETERS

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PREFACE

The Office of the Secretary of Defense, the Military Departments and Defense contractors have for some time been concerned about rising life cycle costs (LCC) of Defense weapon systems.

Over the past two years, the Department of Defense (DoD) has placed new emphasis on examining the projected operating and support (O&S) costs of planned weapons and finding ways to reduce those costs. O&S cost analyses are now a major part of the cost review conducted at each weapon procurement decision meeting by the Defense Systems Acquisition Review Council (DSARC) and the DSARC's principal advisor on new system costs – the Cost Analysis Improvement Group (CAIG).

In support of the DSARC/CAIG review of system O&S cost impacts, LMI was assigned the task: "Life Cycle Cost Analysis in Support of the DSARC." The goal of the task was to develop O&S cost review procedures and estimating methodologies that the DSARC/CAIG will find useful in assessing the cost-effectiveness of new weapon systems. This report is a product of that task. The objective was to analyze weapon systems in the acquisition phase to reduce downstream O&S requirements. The report is offered to military and defense industry cost analysts, as an example of the type of policy-level issues and sensitivities to be addressed during DSARC reviews.

SUMMARY

This study assesses Army helicopter O&S and Support Investment (SI) cost estimating methods to assure that their sensitivity to design and logistic parameters accurately reflects actual outlays experienced. Army O&S cost data sources, methodology, and approaches are examined, and selected cost improvements isolated and evaluated. Strengths of the current costing structure are noted so that they can be carried forward and improved upon to assure accurate representation of new systems to the DSARC. The relation of O&S costs to goals stated in Decision Coordinating Papers (DCP) is highlighted to establish the linkage between cost estimates and DSARC program decisions on new defense systems.

O&S data sources reviewed include reliability, maintainability, and field reported cost data. The present methodology and approaches for both Baseline (Program Manager's) Cost Estimates (BCE) and Independent Parametric Cost Estimates (IPCE) are assessed. The dominant O&S costs are found to be Manpower, Replenishment Spares, and Initial Spares. For Manpower and Initial Spares, simplified models are discussed which give OASD visibility into the critical sensitivities of Army helicopter O&S costs. Of the parameters examined for the selected helicopters, O&S costs are most sensitive to the Mean Time Between Dynamic Component Removals ($MTBR_{DC}$). The report concludes with a discussion of bounding values of Army helicopter O&S cost that can be expected if extreme values of critical O&S cost driving parameters, including those assumed in the cost estimate's approach, are encountered in actual practice. Extreme values of O&S costs are found to be not more than approximately 36% above or below expected O&S costs because, under existing manning procedures, Manpower costs are relatively insensitive to design and logistic parameters (see Table 3).

The principal study conclusions and recommendations are summarized below and underlined in the text for ready reference:

1) Reliability Availability Maintainability/Logistics (RAM/LOG) recorded Maintenance Man Hours per Flight Hour (MMH/FH) should not be the sole source of manpower

estimates made for the Visibility and Management of Operating and Support Costs (VAMOSC) program because they exclude indirect time expended by weapon system personnel (Chapter II).

2) Future Army data sources should include summaries of long-term reliability and maintainability trends for use in cost estimating (Chapter II).

3) The Army should resolve definitional inconsistencies in lower level manpower cost estimates so that BCE and IPCE values will be comparable at these levels (Chapter III, Section A).

4) Indirect manpower is a potential source of cost reduction within the Army provided that careful study is made of optimum indirect manpower levels for the size of the unit supported (Chapter III, Section A).

5) The historic data base for other than Aviation Systems Command (AVSCOM) costs incurred by helicopter units should be displayed in BCEs and IPCEs whenever these costs exceed 20% of the O&S category to which they contribute (Chapter III, Section B).

6) $MTBR_{DC}$ levels achieved should be intensively reviewed to assure a desirable balance between funding for reliability achievement and expected O&S costs (Chapter III, Section B).

7) The Army should develop a resource allocation model to provide a first step toward optimizing vehicle availability by optimizing the choice of initial and replenishment spares purchased (Chapter III, Section C).

8) Weapon system cost estimates should include display of extreme values of O&S costs and the associated field experience values of major driving hardware design and logistic parameters including assumed values (Chapter VI).

ACKNOWLEDGMENTS

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I. INTRODUCTION

For several years the balance among expenditures for Operations and Maintenance (O&M), Procurement, and Research and Development has been shifting toward higher percentages for O&M. The DoD thus faces the challenge of continuing to field new weapons while maintaining high readiness. The cost of maintaining high readiness levels could be reduced by optimal resource allocation and careful planning of future O&M expenditures. This alternative requires weapon system oriented estimates and reports of O&M expenditures that highlight critical areas for management attention. No system now exists to provide such reports, but a number of activities are under way within DoD to meet this requirement. Principal among them are the VAMOSC data systems, aimed at the reporting of actual expenditures by weapon system. Another activity is the inclusion of demonstrable system goals and thresholds in DCPs for DSARC approval, which will influence new systems to reduce O&S costs. The standardization of cost estimates across the services provided by the CAIG Operating and Support and Support Investment Cost Guides represents yet another effort.

Historically, relatively high percentages of Army helicopters' LCC have been consumed in O&S. This is because the required properties for vertical flight - light weight and high vibration – tend to reduce unit costs and increase both scheduled and unscheduled maintenance. Flight safety considerations also increase scheduled maintenance. Furthermore future Army helicopters will carry more sophisticated electronic equipment which tends to fail more often under high vibration. Army helicopter O&S costs are therefore an important area for cost reduction and a good testing ground for improved methods of evaluating alternative resource allocation strategies to reduce O&S costs throughout DoD.

A. OBJECTIVE

The objective of this study was to evaluate alternative Army helicopter O&S cost methodologies and approaches to assure that the degree of hardware design and logistic

parameter sensitivity included in cost estimates accurately reflects actual expenditure sensitivities. The existing methodologies and approaches were assessed through policy level studies which demonstrated the need for linkage of DCP goal values, O&S cost estimates, maintenance concepts, and fielded system cost avoidance. If such a linkage could be established, DoD management would be more confident that O&S cost projections would be achieved, thereby gaining a measure of control over future weapon system O&S costs without sacrificing high levels of readiness.

B. OVERVIEW

Chapter II contains a review and analysis of Army helicopter O&S costs and technical data sources and their applicability to cost estimating. Army helicopter O&S cost drivers are identified and their characteristics investigated. Chapter III presents the study results and two simplified models used to perform O&S cost sensitivity analysis. These analyses are interpreted for DSARC review and special uses of interest to OASD. In Chapter IV, uncertainty methodology and a cost bounding analysis are addressed. This analysis calls for the comparison of extreme values of driving parameters, including assumed parameters, to actual experience and their use in a cost model to create worst case O&S cost estimates.

II. DATA SOURCES

This section describes and assesses the principal data sources for Army helicopter O&S cost analysis. Its purpose is to examine the usefulness of these data sources for future cost estimates, and to indicate the most desirable sources to be developed in the future.

The available data sources for Army helicopter O&S cost estimating may be roughly categorized as general literature, AVSCOM literature, field reporting systems, and official Army publications. The types of data contained in these sources may be engineering estimates, test results, field reported data, or planning factors. Engineering estimates and test results have the advantage of direct applicability to the new system tested or estimated. Field data and planning factors can supply data bases sufficiently large to assure reasonable confidence in the average result.

All these types of data must be assessed and integrated to develop high quality O&S cost estimates. This process requires that the makeup of the low level data elements be established, and care be taken to assure that the data is used to estimate applicable future costs. These guidelines must be applied on a case-by-case basis because each data source and cost estimate is unique.

The principal problem encountered in this assessment is the lack of long–term trend analyses by weapon system of field historic data. Without such a basis, the effects of policy on costs are difficult to distinguish. Army cost and technical data by weapon system were extensively published for only two years of operations. Where each year could be distinguished, the yearly averages were highly erratic. Current emphasis on system cost visibility through the VAMOSC program is important to assure that weapon system trend data becomes available in the near future.

The general literature of helicopter manufacturers and research firms reporting helicopter O&S costs is much less extensive than that for fixed wing aircraft. Helicopter

O&S general literature principally assesses trends in helicopter designs, and their related reliability and maintainability effects. References can be found in the bibliography. The quality of data contained in this source is quite varied depending upon the quality of the research which produced the individual studies.

AVSCOM literature contains the specifics of Army helicopter O&S cost estimating methodology, its justification, and detailed categories of helicopter costs. A knowledge of AVSCOM technical reports is essential to an understanding of Army helicopter cost estimating procedures. These documents supply data for the Cost Estimating Relationships (CER) used in AVSCOM cost models. The types of data contained in the AVSCOM reports may be wartime, peacetime, field reported data, or engineering estimates. Spares costs may include or exclude other command (armament and electronic) parts and may be divided into the budget categories Aircraft Procurement Army (APA, formerly PEMA secondary), and Army Stock Fund (ASF). A review of the assumptions of the data base is therefore necessary to avoid double counting or omissions in the resulting costs.

The principal reporting tools currently available are the Management Summary Reports. Volume I, the Executive Summary Reports, presents highlights of all the volumes. These reports summarize The Army Maintenance Management System (TAMMS) readiness, utilization, reliability, maintainability, flight safety, and field operating cost data. Where applicable, data are subdivided by helicopter functional groups; i.e., Airframe, Power Plant, Rotors, and Transmissions, etc. Since field reports are the source of TAMMS data, many knowledgeable personnel suggest it is subject to inaccuracy due to misunderstanding of instructions, poor memory, and differences in interpretation and motivation on the part of the personnel doing the reporting. Nevertheless, TAMMS data are broadly based, available, and presented at desirable levels of detail. Table 1, for example, uses TAMMS Reliability, Maintainability, and Field Operating Cost data to illustrate dramatically that reliability and maintainability highlighted items are key contributors to cost and that the cost driving subsystems do not vary from helicopter to helicopter.

TABLE 1. WORST HARDWARE SUBSYSTEMS FROM EXECUTIVE SUMMARY REPORTS

In Descending Order
End Item Means Scheduled Maintenance

	OH-58A	UH-1H	CH-47A
Reliability: (Time Between all Maintenance Actions)	End Item Rotors & Trans. Power Plant Misc.	End Item Rotors & Trans. Misc. Airframe	End Item Airframe Misc. Rotors & Trans.
Maintainability: (On-Equipment MMH/FH)	End Item Power Plant Airframe Landing Gear	End Item Misc. Rotors & Trans. Airframe	End Item Rotors & Trans. Airframe Misc.
Cost: ($/FH)	Power Plant Rotors & Trans. End Item Airframe	Power Plant Rotors & Trans. End Item Airframe	Rotors & Trans. Power Plant End Item Airframe
Top 4$ / Total $	.935	.897	.819

Reliability, maintainability, and cost data continue to be reported, but have not been summarized since March 1973. Furthermore, the most interesting cost figures contained in these reports, the Field Operating Cost Analysis, are based on many flight hours but only two years of experience. The failure rates from this data base are used with the latest unit cost figures from the Army Master Data File to produce the data used in the IPCEs. Although the flying hour sample used is large, it does not reflect recent changes in maintenance concepts or utilization rates.

The need to establish contemporary baseline weapon system O&S cost trends for Army systems, led to the initiation of the VAMOSC program which will fill the need for long-term cost trends in the future. The Army has proposed the RAM/LOG system to

support VAMOSC. RAM/LOG was designed to record data during the Government Competitive Tests for the Utility Tactical Transport Aircraft System (UTTAS) and the Advanced Attack Helicopter (AAH). Specifically trained warrant officers record all maintenance events, including direct maintenance man-hours worked, on a set of forms carefully designed for gathering reliability, maintainability, and cost data. The forms allow individual failures to be tracked to the mission events and conditions and subsequent maintenance actions. Detailed failure and maintenance trend analyses can then be performed to facilitate component improvement. Because of the manpower required, RAM/LOG is relatively expensive and the extent of its implementation remains to be decided. <u>In the future RAM/LOG should be the source of long-term trends in reliability and maintainability data. Therefore, planning should include summaries of this data in convenient form to support cost estimates</u>. The use of motivated specific data recorders should provide a high quality of data for that purpose in RAM/LOG.

<u>A major problem in using RAM/LOG for VAMOSC is that it reports direct time only. Non-productive direct and indirect time are not accounted for. While this is ideal for evaluating manufacturers' performance to specifications, it means that additional manpower estimates must be obtained from other sources to account for all chargeable manpower expenditures</u>.

One such source of maintenance manpower estimates is AR 570–2, which will be discussed in detail in Section III. This is one example of the next type of data source, official Army publications. AR 570–2 contains all the authorized factors for generating Tables of Organization and Equipment (TOE), including MMH/FH, and wartime flight rates by aircraft type, and indirect personnel rates. The "Army Force Planning Cost Handbook" contains data on the makeup of existing forces, pay scales, indirect support factors per man, and other useful information. "Military Occupational Specialty (MOS) Training Cost Handbooks" document replacement training expenses by MOS for both officers and enlisted men by budget category. The required formats and standards for Army cost

estimates are described in AP 11–2, 3, 4, and 5 which address respectively, research and development costs, investment costs, O&S costs, and cost standards.

Possibly the most useful data source for the O&S cost sensitivity analyses developed in this study is the Army cost submissions to the DSARC. These assemble in one place the data bases for all parts of the estimate. They are the only documents in which the assumptions required to make the estimate are enumerated. Improvements in these cost estimates can be expected based on improved data available to support approaches and methodologies used in the estimates. Some alternative approaches and methodologies are exercised in this report.

One source of data inaccuracy is inconsistency in the definition of terms used to describe maintenance events and cost elements. This problem is DoD-wide and requires continuing attention. Throughout the remainder of this report, Army conventions will be used. The term "Mean Time Between Failure" (MTBF) will mean flying hours between all field reported component failures, and "Mean Time Between Removals" (MTBR) will mean flying hours between field failures that result in removal of the failed component from the aircraft. The subscript DC will be added to restrict the events considered to those of the dynamic components only. No consistent definition of exactly which components comprise the dynamic components exists, or could exist. Much of the difference in $MTBR_{DC}$ between UTTAS and AAH is explainable by their differing guidelines as to the makeup of the dynamic components. Development of consistent guidelines in this area would improve comparability between Army system estimates.

In summary, extensive data exist on cost and hardware characteristics for Army helicopters. However principal portions of the data are relatively old and based on only two years of experience. Long-term cost trend analysis is a goal of the VAMOSC program and will significantly improve Army cost estimates. RAM/LOG inputs for manpower, however, should be augmented with other data sources to provide indirect manpower chargeable to weapon systems. Planning for RAM/LOG should include summaries of long-term reliability and maintainability trends to support cost estimates.

III. SUPPORT INVESTMENT AND OPERATING AND SUPPORT COST DRIVERS

This section addresses the approaches used to estimate the major influences on Army helicopter SI and O&S costs. The methods used by the Army to make helicopter cost estimates in the major cost categories that dominate SI and O&S cost are summarized. Both BCEs and IPCEs, as referenced in DoDD 5000.4 "OSD Cost Analysis Improvement Group," are addressed. For major weapon systems, Army independent estimates are made at Department of the Army Headquarters level. Selected sensitivities are also calculated to illustrate the methodologies. Quantitative examples in Chapters III and IV are drawn from the UTTAS and AAH BCE and IPCE submitted to the DSARC in November 1976 unless otherwise referenced.

A. MANPOWER

Fifty-nine percent of UTTAS O&S costs and forty percent of AAH O&S costs are influenced by the number of men required to field the fleet. Only about half of this cost is expended for pay and allowances. The remainder is for Permanent Change of Station, Personnel Replacement, and similar Indirect Support Operations costs required to maintain forces in the field. Table 2 illustrates the magnitude of the manpower required by new and existing Army helicopter fleets.

TABLE 2. ARMY HELICOPTER TACTICAL PERSONNEL COMPARISON

- Source: IPCE for UTTAS and AAH

Category	UTTAS		UH-1H		AAH		AH-1S	
	Personnel	%	Personnel	%	Personnel	%	Personnel	%
Pilots	1829	21.9	2176	22.3	801	24.7	963	22.7
Crew Chiefs	914	11.0	1088	11.2	399	12.3	469	11.0
Maintenance Repair	2296	27.5	2912	29.8	892	27.5	1589	37.4
Maintenance Service	921	11.0	1076	11.0	342	10.5	364	8.6
Indirect	2377	28.5	2497	25.7	807	24.9	865	20.4
TOTAL	8336	100.0	9749	100.0	3242	100.0	4250	100.0

This subsection briefly reviews the mission and organization of Army aviation and describes the complexity of Army manpower cost estimating. TOE construction is then illustrated and two allocation procedures are explained. Next, costs for other than pay and allowances and indirect manpower are discussed and a model for sensitizing Army helicopter manpower costs to the driving demand rates for manpower is presented.

Army helicopter missions include: delivery of troops into and outside combat, delivery of supplies and equipment, medical evacuation, observation, reconnaissance, attack of enemy positions and vehicles, and defense of friendly troops and positions. To accomplish these missions several types of helicopters are required simultaneously. Therefore they are assigned to the same company. In practice five company types provide almost all of the helicopter operations within the Army. They are: 1) The Assault Helicopter Company, 2) The Attack Helicopter Company, 3) The Air Cavalry Troop, 4) The Assault Support Helicopter Company, and 5) The Medical Air Ambulance Company. Each must be supported by a sixth company type for intermediate maintenance, usually called a Transportation Aircraft Maintenance Company. These six types of company can be placed within one of the five division types, or in a Corps assigned Brigade, or can be separately Corps assigned. Of the forty-two permutations possible only about thirty actually exist. Each may be individually tailored to suit its individual theater and specific assignment.

Army helicopter organizations are complex, and structuring a combination of units, or force structure, to represent the deployed strengths of a future weapon system is also complex. The UTTAS IPCE, for example, was based on a force structure covering 138 units of 26 types. These units had 92.3% of their helicopters deployed in three of the five major types of units described above.

Each unit in the Army is organized under a TOE. These documents detail the exact organization structure, rank, military occupational specialty, number of men, and equipment authorized for the unit. TOEs for existing units are available in the Military Documents section of the Army Library.

The construction of TOEs is controlled by AR 570–2 and is the responsibility of the Training and Doctrine Command (TRADOC). Chapter 7, Section XI of this regulation contains the MMH/FH authorized for use with the wartime flight rate to establish the number of maintenance repairmen authorized to be in a TOE. Chapter 7, Section X contains annual MMH for Avionics and Aircraft Fire Control maintenance.

When a new system enters the inventory, a new TOE must be designed to suit the MMH/FH and wartime flight rate that apply to the new aircraft. These TOEs are established by the TRADOC school charged with doctrinal responsibility for the unit. They are approved through both TRADOC Headquarters and Department of the Army Headquarters. Once approved, the MMH/FH and wartime flight rate rarely change throughout the life of the system because they are designed to represent wartime experience and subsequent peacetime experience is not directly comparable. Consequently, the number of maintenance men in a TOE generated by these factors rarely changes. As a result TOEs are an excellent representation of actual manpower assigned, regardless of the maintenance experience during peacetime.

The process that leads to determination of these new system MMH/FH factors is a negotiation among user, developer, tester, doctrinal manager, and headquarters. The influence that each participant brings to this negotiation is partly a function of early estimates of the specific hardware design and its performance preceeding the negotiation. For example, if test results support engineering estimates of MMH/FH and the design is stable, use of these factors would be heavily favored. Lack of test support for estimates would lead to highly judgmental decisions on AR 570–2 factors.

Both the AAH and UTTAS manpower estimates are based on TOEs constructed by the appropriate TRADOC school. They can, therefore, realistically represent manpower costs for the weapon systems. The AAH baseline estimate accepted the independent estimate of manpower without change. For UTTAS, however, the BCE estimated 22%

fewer men chargeable to the system than the IPCE. The allocation of personnel chargeable to multiple weapon systems was made by number of aircraft in the IPCE but by workload (MMH per year) in the BCE. Also, a more detailed force structure composition was used in the IPCE. In addition, the BCE excluded indirect manpower at the intermediate level.

The difference between the allocation techniques used for the BCE and the IPCE is attributable to the fact that more than one weapon system is assigned to the typical Army unit. Therefore the cost of personnel who directly maintain multiple aircraft, and the cost of indirect personnel, must be divided between the systems they serve. Table 3 illustrates how these manpower categories fit among all TOE manpower and which ones are policy or reliability/maintainability sensitive.

TABLE 3. ARMY AVIATION TOE PERSONNEL CATEGORIES

<table>
<tr><th>Title</th><th>Impacted by</th><th>Chargeability</th></tr>
<tr><td>Pilots
Crew Chiefs
Flying
Non-Flying</td><td>Policy</td><td rowspan="2">100%
Dedicated</td></tr>
<tr><td>Maintenance Repair
Aircraft Repairmen</td><td>R&M</td></tr>
<tr><td>Component Repairmen
Avionics Repairmen
Armament Repairmen</td><td>R&M</td><td rowspan="3">Allocated
(BCE by
Workload;
IPCE by
Number
of AC)</td></tr>
<tr><td>Maintenance Service
Flight Operations
Fuel Handlers
Technical Inspectors
Aircraft Supply
Others Similar</td><td>Policy and
R&M Indirectly</td></tr>
<tr><td>Indirect
Command Staff
Cooks
Motor Pool
Unit Supply
Others Similar</td><td>Policy</td></tr>
</table>

The UTTAS BCE based the required division of these personnel on the maintenance man-hours expected to be worked on each system by MOS. This procedure required the calculation of approximately five complex workload factors for each TOE in the estimate. The UTTAS IPCE allocated all multiple systems personnel on the basis of the ratio of the number of UTTAS aircraft in the unit to the total number of aircraft. Thus only one simple factor needed to be calculated for each TOE. Further, since many complex factors per TOE were required for the baseline methodology, only three TOEs were used to represent the force structure with fractional numbers of units to model the remainder of the force structure. Conversely the UTTAS IPCE used an extensive force structure (26 TOEs as previously noted) to describe in detail all the smaller units supporting UTTAS operations.

The definitional difference between UTTAS estimates arises from the historic exclusion of indirect intermediate manpower from baseline estimates. The AP 11-4 definition clearly intends that these men be included. For UTTAS this amounted to 199 people or approximately 2% of total UTTAS manpower.

The remaining 20% cannot be divided between the different allocation techniques or the different force structure representations because the results depend on which methodology is changed first. The IPCE generated separate workload allocation factors and applied them in the sensitivity analysis. The result was a change of less than 5%. The factors generated, however, were different from those used by the BCE. If on the other hand, the baseline fractional unit factors are applied to the independent estimate of manpower charged to the three units estimated in the baseline, the result is 5.3% higher than the published baseline estimate.

The most accurate methodology would use the detailed force structure of the IPCE with the complex workload factors of the BCE. If sufficient resources are not available for that much detail, an alternative is to allocate the three most critical units by workload and the remaining detailed force structure by number of aircraft per unit. This

methodology maintains the small unit inefficiency measure of the detailed force structure, while retaining the inherently desirable workload allocation in the majority of units considered. Furthermore, it is consistent with the CAIG guidelines for O&S cost development.

The MMH/FH factors used in the workload allocation factors must be those expected to be published in AR 570–2. They must account for more than contractor obligated MMH/FH to encompass expected Army field experience. Therefore, realistic MMH/FH factors require the AR 570–2 factor negotiation process to be considered although it cannot be quantitatively modelled.

Further clarification of definitions is required below the level of total manpower to assure future consistency at the level Army manpower cost estimates are displayed. These inconsistencies arise from the lack of detail of cost element definitions in AP 11–4 "Operating and Support Cost Guide for Army Materiel Systems." Specifically, crew chiefs and maintenance service (flight operations, fuel handlers, technical inspectors, etc.) were classified as maintenance personnel by the BCE, but as crew personnel and indirect personnel respectively by the IPCE. Table 4 illustrates the resulting classification

TABLE 4. ARMY HELICOPTER PERSONNEL CATEGORY INCONSISTENCIES

AP 11-4 Title	IPCE		BCE	
	Category	Personnel	Category	Personnel
Crew	Pilots Crew Chiefs	1829 914	Pilots	1828
Mainten-ance	Maintenance Repair	2296	Crew Chiefs Maintenance Repair Maintenance Service	914 1484 924
Indirect	Maintenance Service Indirect–Unit Indirect–Inter.	921 2178 199	Indirect–Unit	1357
TOTAL PERSONNEL		8336		6508

inconsistencies and the number of personnel that changed categories. The Army should remove these inconsistencies so that future Crew, Maintenance, and Indirect Pay and Allowance categories will be consistent between baseline and independent estimates.

Manpower costs other than pay and allowances, are estimated using the standard factors available in the "Army Force Planning Cost Handbook" and the "MOS Training Cost Handbooks." No significant differences were found between baseline and independent estimates except in the number of men calculated in each estimate.

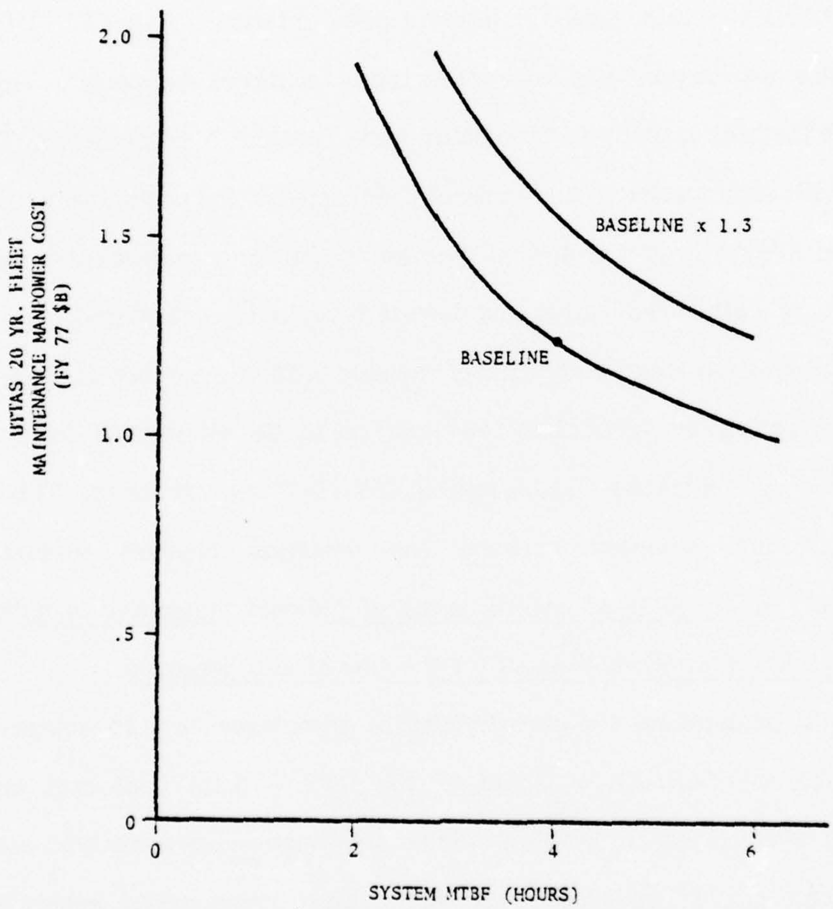
Indirect manpower is a potential area for cost reduction in the Army. For both UTTAS and AAH, the reductions in indirect men relative to the UH-1H and AH-1S manpower levels are substantially lower than those for direct manpower. This is because few AR 570-2 indirect manpower thresholds were crossed in constructing TOEs for the new systems. An examination of the indirect specialties in the preliminary TOEs prepared for UTTAS and AAH showed that 44% of indirect manpower is in specialties for which two or more men are authorized within the lowest level units considered. If this 44% of indirect manpower were treated as linearly variable with the number of direct men in the independent estimate, an additional 325 men could be eliminated from the UTTAS estimate, saving approximately $110.5 million (FY 1977) over 20 years. This reduction is not weapon system oriented because the principal changes involve TRADOC responsibilities. We recommend careful study of indirect manpower in helicopter units with the objective of optimizing support for the size of unit deployed.

In order to understand the sensitivities of manpower cost to equipment demand parameters such as MMH/FH, a model of the UTTAS total O&S cost influenced by manpower was constructed. Scheduled maintenance man-hours were held constant. The unscheduled maintenance man-hours per flight hour which would generate the IPCE estimated number of maintenance men when applied to the UTTAS wartime flight rate, was used with the DCP system MTBF goal of 4 hours to calculate the expected man-hours

failure. This value was held constant and applied to other values of system failure rate to derive the manpower cost at each failure rate. The process was then repeated at increments of MMH/FH to illustrate the effect of underestimated MMH/FH. These variations are illustrated in Figure 1.

FIGURE 1. MAINTENANCE MANPOWER METHODOLOGY

Includes Crew Chiefs & Maintenance Repair Manpower
and Associated PCS, Repl. Trng., & Ind. Support Ops.
Excludes Maintenance Service & Indirect Manpower = $1,226M



Preliminary inconclusive test results indicate UTTAS and AAH are performing significantly better than the baseline MMH/FH, even when standard nonproductive direct and indirect (both) factors are added. Therefore baseline manpower costs are expected to

be experienced, because the fixed initial TOE estimate will remain constant throughout the program. This will occur because no data will indicate too few personnel authorized and no reductions will be considered without wartime experience to support them.

B. REPLENISHMENT SPARES

Replenishment spares represent 33% of AAH O&S cost and 38% of UTTAS O&S cost. The Army definition of replenishment spares cost includes the cost of new items to replace condemned spares, and the overhaul costs of repairable items both in the field and at the depot. Depot overhaul of repairable parts includes both labor and materials. Both ASF and APA parts are included, since no standard method exists for categorizing parts. Rotor blades, for example, may be ASF for one helicopter and APA for another. This definition of replenishment spares is consistent with that used for combat vehicles in the Army, but inconsistent with the written definitions in AP 11–4 and the CAIG aircraft O&S cost guidelines (reference 3) both of which exclude depot costs. The Army should correct this situation by conforming to its own definition in future estimates.

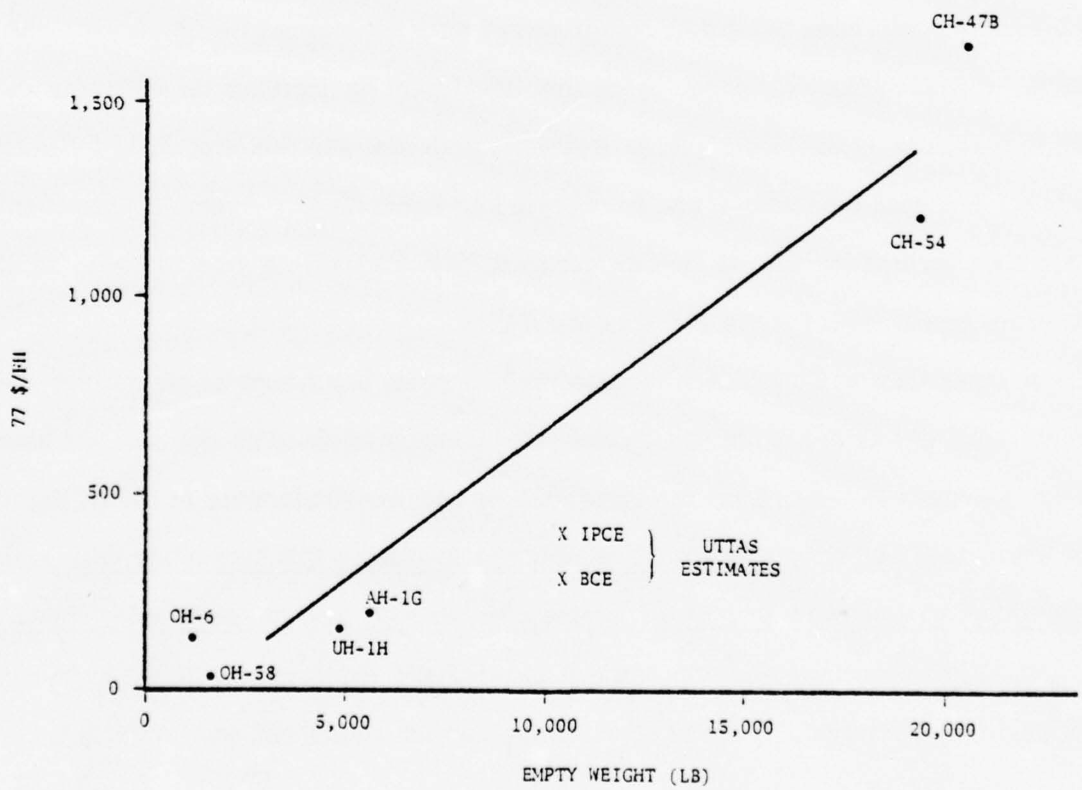
BCEs of replenishment spares costs are developed by building up all costs for dynamic components through individual estimates of both new and overhaul costs for each component. The exact equations are enumerated in Appendix C. Dynamic component totals are then divided by historic factors deduced from TAMMS data to estimate total replenishment spares costs for the airframe and engine.

Costs other than AVSCOM costs incurred by helicopter units, such as electronics and armament costs, are estimated by their respective commands based on the cost per year of similar systems. The data base for these costs is not brought forward in the BCE and was not evaluated. <u>All programs should be required to display this supporting data base whenever other command replenishment spares costs exceed 20% of total replenishment spares cost</u>. This procedure will allow the quality of the data base to be evaluated in cases of significant interest. Because of extensive mission equipment and armament, the

AAH, for example, estimated 51% of Replenishment Spares and 61% of Consumption costs without this supporting data.

IPCEs use historic costs of fielded helicopters plotted against empty weight to form a CER which is entered at the new helicopter empty weight. This value is then reduced by a reliability adjustment factor which accounts for a reduced number of failures in the dynamic components. Two CERs are generated, one for APA costs and one for ASF. The basis for these CERs is the failure data in the "Executive Summary Reports" updated to reflect current costs of components. Figure 2 shows the data and CER line for the sum of these APA and ASF costs. The reduction from the CER line to the IPCE UTTAS estimate shown in Figure 2 represents the reliability adjustment.

FIGURE 2. IPCE REPLENISHMENT SPARES DATA BASE
(ASF & APA - Airframe & Engine)



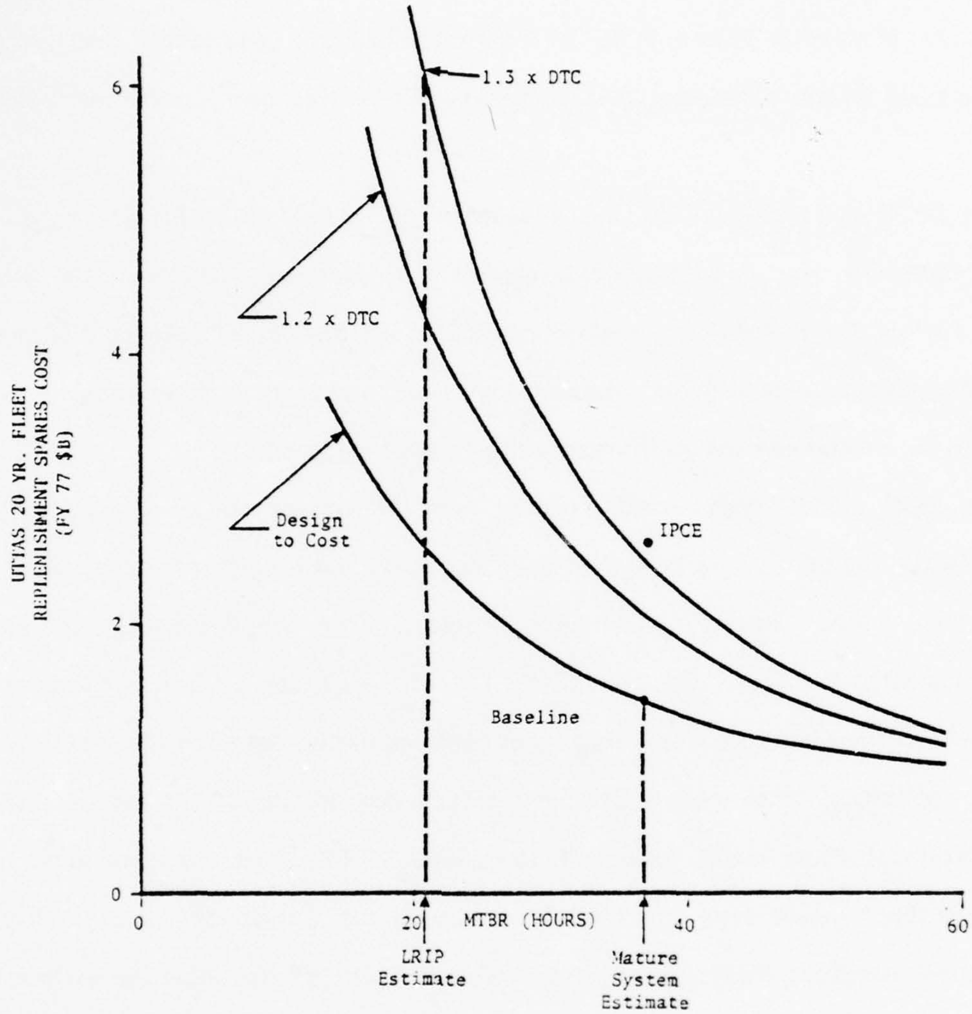
The reliability adjustment factor assumes 20% of replenishment spares costs are fixed and the remaining 80% are linearly proportional to the number of failures in the dynamic components. No substantiation for this 80–20 division is presented. Furthermore, contractor values of design inherent MTBR are used rather than the Army's estimated field MTBR. The result is a reduction of 40% (factor = .6) for both UTTAS and AAH.

The IPCE methodology has the advantage of inherently including unpredictable unknown factors insofar as they are reflected in the data base. However, the data base does not reflect the change to a new generation of helicopter technology. Furthermore, the reliability adjustment is grossly estimated at best, and there is no adjustment for cost changes to obtain the new reliability and other technology levels.

The BCE methodology accommodates new technology well. Furthermore, the historic factor for percent of cost contained in the dynamic components is supported by detailed data in the "Executive Summary Reports." The only remaining problem is to account realistically for unknown factors in the analysis. Cost estimates must realistically reflect average new and repair costs expected over the 20-year life of the program. $MTBR_{DC}$ must include factors for field degradation of the test environment. Consideration of these costs, logistic factors, and $MTBR_{DC}$ at the component level is highly desirable because they may be compared to actual component tests, with planned modifications carefully analyzed, to yield a judgment of how reasonable the estimate is.

The sensitivity of this calculation is illustrated in Figure 3, which shows the result of varying all dynamic component $MTBR_{DC}$ by linear factors and recalculating total costs. The calculation is then repeated with 20 and 30% growth in material cost. These two factors combine to create over a billion dollars difference in 20-year life cost within reasonable variations of the input parameters. Therefore, $MTBR_{DC}$ achieved in the field and parts cost growth should be intensely reviewed in order to allocate resources to achieve reliability if potentially unacceptable O&S cost growth is predicted.

FIGURE 3. UTTAS REPLENISHMENT SPARES COST SENSITIVITY
(914 Aircraft - 324 Flight Hours/Year/Aircraft)



Furthermore, this calculation should be performed on all Army helicopters to evaluate the importance of Replenishment Spares cost sensitivity. The AAH, for example, was reviewed and found not sensitive to $MTBR_{DC}$ primarily due to the requirement for less than one third the programmed flight hours of the UTTAS.

In assessing $MTBR_{DC}$ reliability growth, a number of factors must be considered. Fielded helicopters have all been subject to maximum Time Between Overhual (TBO)

constraints. Eliminating the data on removals due to reaching maximum time value is nearly impossible on the basis of reported information. Furthermore, TBO values themselves often grow, thereby causing growth in the average $MTBR_{DC}$. Also the effects of infant mortality and maintenance personnel learning, if not identified, can give the impression of apparent growth without real improvement in component performance. An excellent analysis of the $MTBR_{DC}$ growth phenomenon can be found in IDA Study S-451 (reference 7). That study indicates that many components illustrate growth and many illustrate decay. When the factors mentioned above are included, the apparent result is a growth in net reliability. Careful examination of the IDA data indicates highly erratic time histories in both component reliability growth and decay. Therefore, specification of reliability growth achieved should be based on an analysis of the component level and the environment in which it occurred.

The achievement of reliability growth in the field can be related to the expenditure of resources specifically for that purpose. Examples of such resource allocations that have resulted in reliability growth are engine component improvement programs and modification programs leading to a new lettered series of an existing model helicopter. Engineering Change Proposals (ECP) have also demonstrated reliability growth potential. The achievement of this potential has often been blunted, however, by higher priority needs for resources. For example, funds for improvement of a UH-1H gearbox were denied in FY 1975 even though a Major Item Special Study (reference 19) showed a conservatively estimated savings potential averaging $314,385 per year. The greatest number of ECPs have been related to flight safety and performance improvements, and should also be considered as a means of achieving greater reliability growth in the future.

C. INITIAL SPARES

A third key cost driver of SI and O&S costs is initial spares. Cost analysts define this category to include all spares bought to maintain system availability during the repair or reprocurement cycle, regardless of when the associated aircraft are purchased. Budget

analysts use a definition based on DoDI 4140.42, "Determination of Initial Requirements for Secondary Item Spare and Repair Parts," which includes only those spares needed during a short initial period not to exceed two years beyond establishment of preliminary operational capability. This definitional difference makes evaluation of cost analysis data using budget figures difficult. In this section we will deal with initial spares primarily as defined by the cost analyst and reference other definitions clearly when applicable. This section addresses methodology in use in the Army to estimate initial spares costs, problems in the interpretation of the results of that approach, and a means to alleviate the problem.

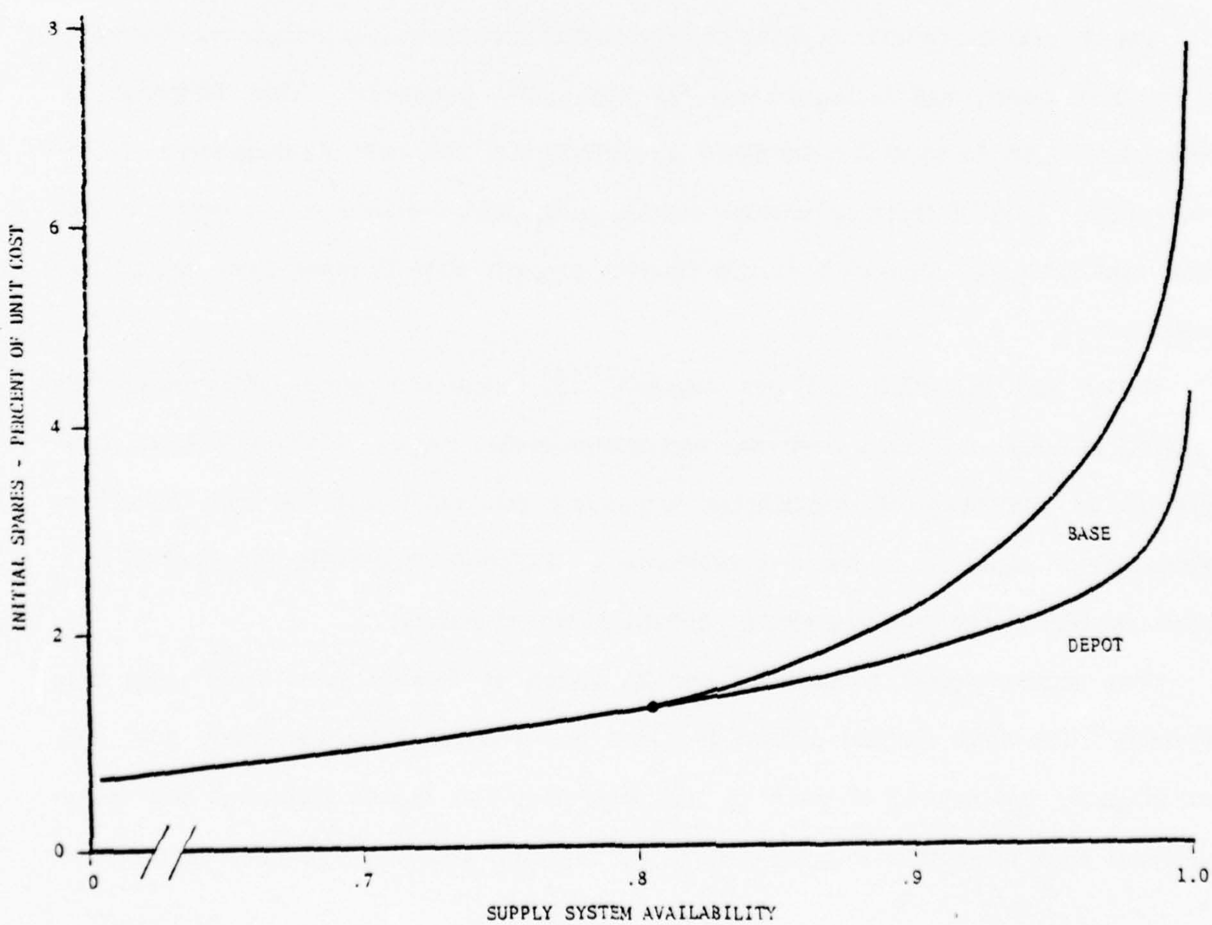
Both BCEs and IPCEs determine initial spares costs by multiplying historic factors times the production cost of the installed hardware. We were not able to locate any analyses that describe the data base and techniques used to derive these historic factors for components in the airframe, engine, electronics, or armament. Therefore, we were unable to assess the underlying assumptions of these factors. We presume they represent a continuation of past concepts and practices at all levels.

A few adjustments have been made to these factors in recent Army estimates. These adjustments reflect reductions in spares required because of expected high reliability and differences between early and later production rates. None of these adjustments has explicitly addressed the Not Operationally Ready Spares (NORS) level expected to be achieved by the supply system for the investment in initial spares. These methods assume implicitly that the Army's requirement of 80% availability for UTTAS and AAH will be reached. Historical worldwide standards for operational ready rates reported in Executive Summary Reports range from 66% to 74%. The Army requirement is therefore an optimistic goal, a fact which is not considered in their estimate.

A number of models exist that estimate initial spares costs to obtain a specified level of weapon system availability. These include the Air Force AFLC Logistics Support Cost Model, the Air Force Mod-Metric Model, the TASC OMEGA Program Model and the

LMI NORS Availability Model. All require extensive input data and use various optimization techniques. The best model for DSARC-level analysis would explicitly relate availability to initial spares investment, while minimizing required inputs without sacrificing significant considerations. Some detail must necessarily be foregone in order to reduce the number of inputs required. Such a model was constructed in the course of this task and is described in Appendix B. Results using hypothetical data are shown in Figure 4. This figure illustrates a typical sharp rise in required investment to achieve high levels of supply system availability (the component of system availability due to the supply system). This model will continue to evolve as new applications are run and new simplifications of more detailed models are devised.

FIGURE 4. HYPOTHETICAL EXAMPLE OF INITIAL SPARES OPTIMIZATION MODEL



No optimum resource allocation technique was found in the Army spares budget process, either for initial or replenishment spares. A model using the optimization criteria set forth in Appendix B could lead to both higher system availability and lower spares cost. Furthermore, both initial and replenishment spares could be optimized. Therefore, a long-range goal of the Army should be to devise and implement a means of allocating spares budgets optimally to obtain the maximum availability for military essential aircraft.

D. OTHER COSTS

This section briefly describes depot, modification, and ammunition cost estimates as developed by the Army for helicopters. These costs are representative of O&S cost drivers of lower sensitivity, magnitude, and potential for cost reduction than those of the first three sections of this chapter.

Depot costs as included in Army helicopter O&S cost estimates include only the cost of material, labor, and transportation for high time overhauls. This definition is inconsistent with AP 11-4 and the CAIG aircraft SI and O&S cost element structure in reference 3. Both of these definitions include component overhaul at the depot in the depot cost category. Section B of this chapter suggests ways to make these categories consistent.

Labor and material cost per overhaul are estimated using CERs based on correlations between historic cost data and system empty weight. These CERs are then adjusted on the basis of engineering judgement for maintainability and reliability improvements expected in the new helicopters. Current labor rates are applied and escalation factors are used to arrive at current dollar estimates.

Two methodologies have been used to arrive at 20 year costs from costs per overhaul. The first method divides the cost per overhaul into the yearly cost and multiplies by the number of years in the program. The second estimates how many overhauls each aircraft will experience in its lifetime, and their cost. No overhaul at

completion is assumed. This assumption does not account for transition to the National Guard or other use after Army phase-out which would immediately result in an overhaul. Nor does it account for the overhauls that aircraft with a high use rate would undergo near the end of their lifetime. The yearly calculation should therefore be used in future estimates of depot cost.

Use of the Uniform Depot Maintenance Cost Accounting and Production Reporting System (RCS DDI&L(A) 911) has been considered and was implemented for the Army VAMOSC submission of FY 1975 costs. This system is desirable because it is consistent with the CAIG aircraft SI & O&S cost guidelines and the other services. A problem exists because overhaul costs of components removed during overhaul of airframes are estimated at standard prices rather than actual cost. Actual cost is reported separately under the cost of repairing the component and is used to formulate the next year's standard price. This creates a double counting of component repair cost if aircraft and component costs are simply added together. The standard cost is impossible to remove in the current system since it is not reported for many components. Hence, further effort is required before the 911 reports can be accurately used to estimate depot costs of Army helicopters.

Modification costs for Army helicopters throughout their lifetime are estimated by the IPCE to be 2% of production costs. This estimate includes only modifications that do not change the series designation (last letter) of the helicopter being estimated. BCEs often omit modification costs completely. Actual expenditures reported in budget documents for Army helicopter modifications have exceeded both spares parts and new aircraft expenditures for the last five years at least. If these data are accurate, there must be large expenditures to modify helicopters to new series designations. Since such modifications are life cycle costs to the weapon system, they should be accurately reflected in the BCE and IPCE cost estimates. No acceptable methods now exist to estimate total system modification costs because of the unpredictability of their initiation

and approval. A thorough study of this area should include the relationships of modifications to the type of aircraft, the predicted reliability and maintainability levels, and the adaptability of the aircraft to other missions. Until such a study accurately reflects all modification costs, only within series modifications could be replaced with average modification costs including model changes for each type of Army helicopter based on past budget analysis. Another solution would be to consider system life to be only the life of the average series rather than the complete model of a helicopter.

Unit Training Ammunition costs for the AAH were estimated by the BCE and IPCE to be 15% and 24% respectively of O&S costs. Both estimates were developed from the same annual use rates per aircrew. One difference was in the types of ammunition assumed. One estimate used standard 30 mm ammunition while the other used NATO compatible 30 mm ammunition. The type of missile, either training or fully armed, was another variable. These differences were sufficient to account for the 9% variation in O&S cost noted above. No justification of the assumptions made was contained in either estimate. Without this knowledge, such large deviations cannot be resolved. This illustrates the specific knowledge necessary to retain evaluation capabilities of estimates of this type. Information such as this should be included in the System Program Definition Statement (SPDS) recommended in the CAIG aircraft O&S cost guidelines (reference 3).

In summary, the Army uses equipment related parameters such as MMH/FH and $MTBR_{DC}$ to estimate key O&S cost driving categories. High level sensitivities required new models in the manpower and initial spares categories but the replenishment spares BCE methodology was acceptable as formulated by the Army for sensitivity studies. Although manpower and replenishment spares were both of large magnitude, replenishment spares showed much greater sensitivity because of the institutional tendency to hold manpower at the initially established level. The most sensitive parameter studied was $MTBR_{DC}$. Inconsistencies need to be resolved in manpower

category definitions. Indirect manpower was found to be a source of potential cost reduction. Historic data bases for other than AVSCOM costs need to be displayed whenever they exceed 20% of the replenishment spares category. Finally, a resource allocation model should be developed by the Army to optimize investments in initial and replenishment spares.

IV. O&S COST BOUNDARIES

This chapter addresses the uncertainties in inputs and approaches to O&S cost that should be considered when relating Army O&S cost estimates to the range of expenses that may be incurred through budget expenditures in later years. In Section A, three approaches to cost uncertainties are discussed and placed in perspective. Uncertainities relating to demand rates are highlighted in Appendix C, using the first of these approaches because these demand rates are the principal drivers of logistics cost uncertainty. In Section B, assumption uncertainties are discussed and specific examples for UTTAS and AAH are constructed to illustrate possible high and low extremes of O&S cost expenditures and the associated probability of their occurrence.

A. UNCERTAINTY ANALYSIS

The term "Uncertainty Analysis" refers classically to the mathematical calculation of the probability density function of the result of a process given the probablistic nature of the inputs to the process. In the field of cost analysis, results are summed to form total costs. Therefore, the most important operation is the sum of random cost variables. The Central Limit Theorem tells us that the mean of a sum of random variables is the sum of the random variables' means. Therefore, given a point cost estimate made up of component costs, and given component costs probablistically constructed to have a mean value of the point estimate of that component, then the mean of the sum of the components will be the point cost estimate. The dispersion of the estimate, however, will depend upon the dispersion of the component estimates. This dispersion will occur around the mean of the point cost estimate. Uncertainty analysis of this type is subject to exactly the same assumptions as the analysis that led to the point cost estimate.

This approach to uncertainty is used in an Appendix of Army IPCEs to satisfy the AP 11–4 requirement for uncertainty analysis. Costs are assumed to be Weibull

distributed with dispersion of the cost estimated from the analyst's judgment. The methodology is the same regardless of how the cost was originally estimated.

Uncertainty in the assumptions supporting the point estimate also affects O&S cost estimates. Analysis of this type of uncertainty is addressed by Army IPCEs in another Appendix called "Cost Sensitivity Analysis." Simple changes in assumptions are enumerated and put through the cost equations to estimate the total impact of the change. No standard set of sensitivity analysis is defined for these analyses. No closed set of alternatives would be desirable considering the diversity of the systems being costed. Questions of force structure, company size, flying-hour program, allocation factors, and replacement by reference existing systems are addressed. However, the increments selected represent only very small deviations from the baseline assumptions. The AAH sensitivity analysis, for example, continued 12 such studies. The greatest of these 12 resulted in a variation of 8% and the second greatest 3.8% of total O&S cost. Several of these 12 studies are suitable for projection to greater variations through interpolation. This process, however, is left to the user.

The missing link in this analysis is the comparison of assumed values in cost estimates to values experienced on operational systems. For example, flying hours in the AAH IPCE are decreased from 240 hours per year per aircraft to 230 hours. However, pre-fuel crisis flight hours per year as reported in Executive Summary Reports for the AH-1G are 180 hours. This chapter takes a step toward completing this analysis in Section B by illustrating how this link to existing systems might be added.

A third source of uncertainty in O&S costs is the constraints of the budget approval system, especially in Replenishment Spares. Limitations on funds available, or higher priorities for other programs can cause spares expenditures to be reduced below requested levels. If expected demand then materializes, existing stocks must be drawn down or availability levels reduced. Although data on requested budget levels are available, no detailed summary could be found to enumerate actual expenditures or authorized budget

authority by weapon system. Comparison of Aircraft Procurement Army Spare and Repair Part budgets submitted to Congress and actual expenditures reported with later year submissions reveals a growth trend in expenditures between 1972 and 1976 but highly accurate early year estimates. These characteristics would be expected in an account in which expenditures are controlled to assure agreement with estimates. Therefore, it is more likely that this uncertainty would result in a decrease in funds expended on a weapon system rather than an increase. This is because both the request would have to be above initially estimated levels, and the budget limit not sufficiently impacted to result in greater than estimated expenditures. Unusually high demand rates in high priority systems could nonetheless still cause expenditures greater than planned. Further analysis of this effect would require more detailed investigation of the Army budget process than was possible within the resources of this task.

B. ASSUMPTION UNCERTAINTIES

The assumptions upon which Army O&S cost estimates are based are enumerated in the cost estimating documents (BCE and IPCE) and supported in detail in the Army Material Requirements Specification. These assumptions include the flying hour program, the force structure, and the Maintenance Concept. A number of these assumptions are varied in the sensitivity analysis of the IPCE. No estimate is made, however, of the worst or best values of the assumption for use in extending the sensitivities to a worst case uncertainty analysis. This section discusses such an extension of these sensitivities to bounding worst case outcomes and assesses the possible O&S cost results for UTTAS and AAH. The following paragraphs enumerate the critical inputs assumed for this analysis.

The flying hour program costed for both UTTAS and AAH exceeds the reported flying hours of existing helicopters by over 30%. Furthermore, the energy crisis will be increasing fuel prices in the future. Therefore, a reasonable estimate of flying hours expected over the next twenty years could be significantly below that of the Army's cost estimates. For UTTAS, we chose a low bound of 200 hours per year. Baseline flight hours

were used as the upper boundary value. For AAH, boundary and expected values of 120, 180, and 240 (baseline) were used.

Estimated MTBR values also may not be achieved in the worst case because of lack of budget support for test and correction programs and ECPs, or because of unexpected engineering problems. At least those levels already demonstrated in tests can be expected to be demonstrated. A small amount of further growth can be expected due to simple no cost corrections and those changes already initiated that have not yet impacted test results. For UTTAS, we chose a low cost extreme (high MTBR extreme) of the baseline $MTBR_{DC}$, 36.7 hours, an expected value of 32 hours and a high cost extreme of 28 hours. Comparable values for AAH selected were 45.7, 37.0, and 30.0 hours. These selections were based solely on a subjective assessment of the typical unknown occurrences in the average program.

Design-to-Cost growth in the unit cost of new spares and repair parts can also cause significant cost growth in systems with high demand rates. For both UTTAS and AAH, we chose a low extreme value of no design-to-cost growth and both an expected and high extreme value of 1.2. This value is considered reasonable within the context of already reported costs.

Years between depot overhauls are also forecast to change significantly for this analysis. A high cost extreme value of 60% of the baseline was selected for both UTTAS and AAH, reflecting the influence of existing experience on this input value.

Initial spares were also reduced 20% based on experience using the initial spares model of Chapter III. This is the value we judge could be saved by application of a resource allocation model.

Tables 5 and 6 display the results of this boundary analysis for UTTAS and AAH respectively, compared to the late 1976 BCE. These tables show that even in the worst possible case, only a 36% increase in O&S cost could be expected. This rather low variability in O&S cost is attributable to the insensitivity of manpower costs, which are sized for wartime peak requirements.

TABLE 5. UTTAS O&S COST RANGES

	BCE	Low Extreme	LMI Expected	High Extreme
ASSUMPTION				
Flying Hours per Year	324	200	250	324
$MTBR_{DC}$	36.7	37.6	32	28
DTC Growth	1.0	1.0	1.2	1.2
Years/Depot Ovhl.	10	10	10	6
COST (FY 77 $M)				
Manpower	1,767.8	1,767.8	1,767.8	1,767.8
Consumption				
Repl. Spares*	1,440.3	889.1	2,029.6	3,220.0
POL	401.0	247.5	309.4	401.0
Depot	307.6	307.6	307.6	512.7
Ind. Support Ops.	1,294.8	1,294.8	1,294.8	1,294.8
Initial Spares	305.6	244.5	305.6	305.6
Total	5,517.1	4,751.3	6,014.8	7,501.9
% of BCE		-14	+9	+36
Likelihood of Occurrence	Moderate	Unlikely	Moderate	Very Unlikely

*Avionics costs assumed proportional to dynamic components costs

TABLE 6. AAH O&S COST RANGES

	BCE	Low Extreme	LMI Expected	High Extreme
ASSUMPTION				
Flying Hours Per Year	240	120	180	240
$MTBR_{DC}$	45.7	45.7	37.0	30.0
DTC Growth	1.0	1.0	1.2	1.2
Years/Depot Ovhl.	10	10	10	6
COST (FY 77 $M)				
Manpower	883.6	883.6	883.6	883.6
Consumption				
Repl. Spares*	1,300.6	650.3	1,847.4	2,278.4
POL	114.6	57.3	85.9	114.6
Depot	129.8	129.8	129.8	216.3
Ind. Support Ops.	540.2	540.2	540.2	540.2
Initial Spares	267.9	214.3	267.9	267.9
Total	3,236.7	2,475.5	3,754.8	4,301.0
% of BCE		-24	+16	+33
Likelihood of Occurrence	Moderate	Unlikely	Moderate	Unlikely

*Avionics, Mission Equipment, and Armament costs assumed proportional to dynamic component costs.

We also assessed the cost reduction from the UTTAS BCE possible with more efficient indirect manning, optimum initial spares, and consolidating MOS 68s in units that fly UTTAS only. For this analysis, 44% of indirect personnel were varied linearly with the number of other personnel, initial spares costs were reduced 20%, and all MOS 68 MMH/FH were treated as applicable to one specialty. Table 7 shows the results of this cost study. The expected savings from these more efficient policies is 3% of O&S cost.

TABLE 7. UTTAS O&S POLICY ALTERNATIVES

	BCE	Most Efficient Policy
ASSUMPTION		
Indirect Men	Per AR 570-2	44% Variable
Initial Spares	Historic	Optimum
MOS 68s at AVUM	One Each	Consolidated
COST (FY 77 $M)		
Manpower	1,767.8	1,707.0
Consumption		
Repl. Spares	1,440.3	1,440.3
POL	401.0	401.0
Depot	307.6	307.6
Ind. Support Ops.	1,294.8	1,252.3
Initial Spares	305.6	244.5
Total	5,517.1	5,352.7
% of BCE		-3

The extreme values of O&S cost illustrated here, including major excursions in assumed and independent driving parameters, will aid DSARC level policy planners in assessing the variability of the program under review. Furthermore, comparison of values used to field experienced values will serve to validate the estimate or require supporting explanation of the values used in the baseline. Therefore, all weapon system cost estimates should include these extreme values of O&S costs identified with the generating parameter values, and an assessment of the probability that the combined set of values will occur.

APPENDIX A

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APPENDIX B

THE SIMPLIFIED OPTIMUM INITIAL SPARES MODEL

During this task a model was designed for estimating initial spares costs as a function of supply system availability. This Appendix describes the model in detail and discusses its strengths and weaknesses.

The Simplified Optimum Initial Spares (SOIS) Model was designed to combine several unique qualities of the large models referenced in Chapter III, Section C. The principal criterion for establishing this model was to simplify the required inputs without sacrificing major accuracy of the solution.

The SOIS model relates the contribution of the supply system to weapon system availability, to the cost of spares purchased to support the weapon system. This relationship requires the calculation of the probability that the aircraft will be down due to lack of a spare part, whether classified NORM or NORS. Another way to define supply system availability would be, the fraction of aircraft which do not have holes in them at a random point in time. The probability that the aircraft will be down due to lack of maintenance is not considered. Furthermore only the Line Removable Unit (LRU) level is considered for simplification.

The supply system availability is calculated by assuming LRUs will fail according to a Poisson distribution during a given flight hour program. Starting with no spares the expected number of backorders is calculated for each component from the given failure rate. This result is divided by the items in use (quantity per aircraft times inventory) to obtain the probability that the helicopter will be down due to a lack of the component. The total system probability of being up due to the supply system is then the product of one minus this probability of being down for each subsystem or component. In equation form this may be written:

$$Q = \pi q_i$$

where:

Q = Probability the system is available as a function of the supply system (see text for more detail)

$$q_{i,N} = \left(1 - \frac{EBO_{i,N}}{QPA_i \cdot I}\right)^{QPA_i}$$

and:

i = Subscript for each component

$EBO_{i,N}$ = Expected Back Orders = $\sum_{j=N+1}^{\infty} P_j(j-N)$

where:

N = Number of Spares

$P_j = \frac{(\lambda t)^j}{j!} e^{-\lambda t}$, the probability of j failures at failure rate λ within turnaround time t.

QPA = Quantity Per Aircraft

I = Inventory of Aircraft

This treatment has been fully developed in LMI Report 72-3, "Measurements of Military Essentiality."[1] The optimum choice of the next spare to buy at each point is given by the spare with the largest value of the expression:

$$\ln \left(q_{i,N+1}/q_{i,N}\right) / COST_i$$

where:

$COST_i$ = the unit cost of the i^{th} component

The model continues to buy the next optimum spare and traces the growth of Q, the supply system availability versus total cost of all spares. The mathematics guarantees that this cost is minimum for obtaining the corresponding supply system availability.

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[1] August 1972, AD 748621

The major simplification of this model is the use of one time t to represent the average steady state time to achieving a ready-for-issue spare after a failure. To estimate base spares required, this time value should be a combination of the base repair cycle including all queueing and administrative time, and the depot order and ship time, weighted respectively by the base repair and depot repair fractions.

The model then estimates the depot spares required using the LSC Model equation:

$$C_D = \sum_{i=1}^{NS} \frac{FH \cdot QPA_i COST_i \cdot DRCT_i NRTS_i}{MTBR_i}$$

where:

C_D = Cost of Depot Initial Spares

NS = Number of Subsystems or Components

FH = Peak Fleet Flying Hours Per Month

DRCT = Depot Repair Cycle Time (Months)

NRTS = Not Repairable This Station Fraction

MTBR = MeanTime Between Removals

Use of this equation corresponds to buying enough spares to fill the depot pipeline once. This simplification assumes that depot stocks are not a major portion of required initial spares. If depot stocks are a major portion of required initial spares, the model may be rerun with one base supporting all aircraft and with depot turnaround time plus order and ship time replacing base turnaround time. This approximates depot spare requirements.

This model has been programmed in approximately 100 FORTRAN statements and operates in the time-sharing mode on the CDC CYBERNET System. An example of the output using hypothetical data is illustrated in Figure 4, Chapter III, Section C.

Studies have shown that this model is very sensitive to the level of data input. Therefore all LRUs should be included for the system or subsystem under study. If a

subsystem alone is addressed, the Supply System Availability level must be carefully analyzed to assure that it is a reasonable level for the situation under study.

The SOIS model is expected to continue to evolve as new applications are encountered and new simplifications of more detailed models are devised.

APPENDIX C

DEMAND DRIVEN UNCERTAINTY

The most uncertain variables impacting Army helicopter O&S costs are the demand rates which will determine the consumption of the system's resources. This appendix illustrates how uncertainty in one of these demand rates, $MTBR_{DC}$, can be addressed directly through classical uncertainty analysis. The analysis illustrates that dispersion in component hardware parameters can be related to their effect on O&S costs.

Mean Time Between Removals is the driving demand rate in replenishment spares costs. Army predicted values of MTBR in the field for dynamic components of new helicopters are twice those experienced in the field today. Growth toward these values is underway, but as yet little confidence can be placed in this growth because of the relatively few hours of flight time accumulated. Therefore the distribution of costs that result from a distribution of MTBR values is required to assess the possible cost excursions resulting from inaccurate MTBR estimates.

The BCE equation for replenishment airframe and engine spares cost may be reduced to:

$$C_{RS} = \frac{1}{PDC} \sum_i \frac{(W_i \times C_{NEW_i} + (1 - W_i)\ C_{OVHL_i})\ QPA_i}{MTBR_i}$$

where:

C_{RS}	=	Cost of Airframe and Engine Replenishment Spares.
i	=	Subscript increment for each Dynamic Component.
PDC	=	Percent of Cost represented by Dynamic Components.
W	=	Washout (Condemnation) Rate.
C_{NEW}	=	Cost of a new Spare.
C_{OVHL}	=	Cost of Parts and Labor to Overhaul a Spare.

QPA = Quantity per Aircraft.

MTBR = Mean Time Between Removals.

Since all the variables will be held constant for this analysis except MTBR, this equation may be reduced to:

$$C_{RS_i} = \frac{K_i}{MTBR_i}$$

for each component. This equation is treated in elementary random variable texts[2] with the result that the probability density function of C_{RS_i} is given by the following equation:

$$f_c(C) = \frac{|K|}{C^2} f_M\left(\frac{K}{C}\right)$$

where:

$f_c(C)$ = The Probability Density Function of Cost.

K = Combined variables held constant

$$\frac{(W_i\, C_{NEW_i} + (1 - W_i)\, C_{OVHL_i})\ QPA_i}{PDC}$$

C = Value of Cost at which Probability is Evaluated.

$f_M(\frac{K}{C})$ = Probability Density Function of MTBR evaluated at $\frac{K}{C}$

If MTBR is uniformly distributed between a low value M_L and a high value M_H then $f_c(C)$ is given by:

$$f_c(C) = \frac{K}{C^2\,(M_H - M_L)} \quad \text{in the range } \frac{K}{M_H} \leq C \leq \frac{K}{M_L}$$

Evaluating the mean, $\bar{C}$, and the mean squared value, V, we obtain:

$$\bar{C} = \frac{K}{M_H - M_L} \ln \frac{M_H}{M_L}$$

$$V = \frac{K^2}{M_H\, M_L}$$

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[2] See for example <u>Probability Random Variables, and Stochastic Process</u>, by A. Papoulis, McGraw Hill, 1965, p. 128.

The variance, S^2, can now be found from the well known[3] relationship:

$$S^2 = V - \bar{C}^2$$

Since many distributions are added, the Central Limit Theorem assures that the distribution of the result is normal with the mean equal to the sum of the component means, and variance equal to the sum of the component variances. The mean plus the standard deviation (square root of the variance) may now be plotted for any assumption about the relationship of M_H and M_L. The region below this curve contains 84% of all possible outcomes.

Figure C–1 illustrates the results of assuming UTTAS MTBR is uniformly distributed around the Army estimates with ranges of ±15% and ±30%. This graph shows the calculation for several values of system $MTBR_{DC}$ by assuming equal linear multiples of all component MTBR estimates. From this figure uncertainty in the mean and uncertainty in the dispersion can be compared to assess the probability of growth or reduction in replenishment spares cost.

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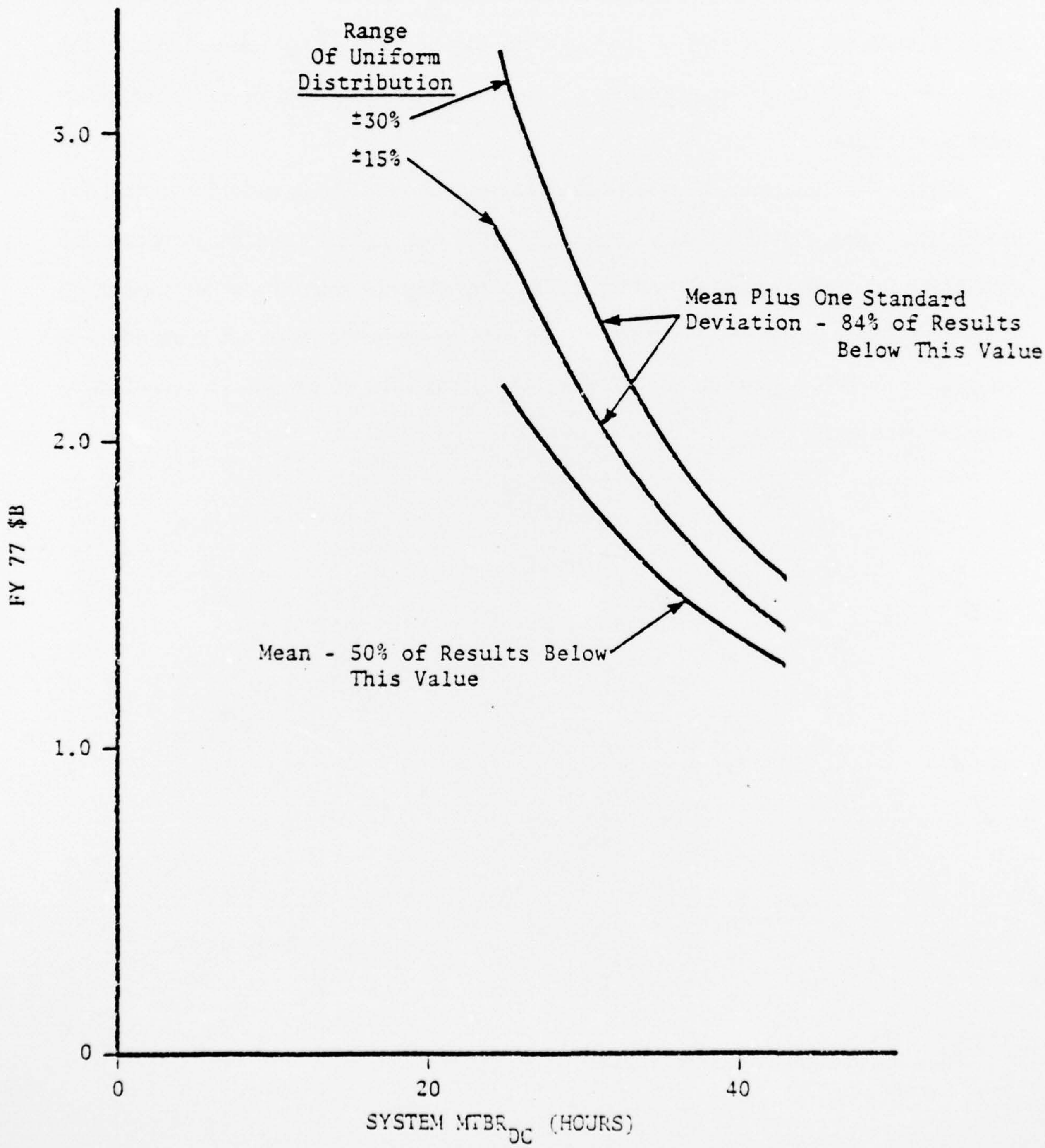
[3] See for example, Papoulis, p. 144.

FIGURE C-1. UTTAS REPLENISHMENT SPARES DEMAND DRIVEN UNCERTAINTY

Each Component MTBR
Uniformly Distributed
Around Army Estimate



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study assesses Army helicopter O&S costs and Support Investment (SI) costs in order to assure that the degree of hardware design and logistic parameter sensitivity included in cost estimates accurately reflects actual expenditure sensitivities. Army O&S cost data sources, methodology, and approaches are examined, and selected cost improvements isolated and evaluated. Strengths of the current costing structure are noted so that they can be carried forward and improved upon to assure accurate representation of new systems to the DSARC.

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The relation of O&S costs to goals stated in Decision Coordinating Papers (DCP) is highlighted to establish the linkage between cost estimates and DSARC program decisions on new defense systems.

O&S data sources reviewed include reliability, maintainability, and field reported cost data. The present methodology and approaches for both Baseline (Program Manager's) Cost Estimates (BCE) and Independent Parametric Cost Estimates (IPCE) are assessed. The dominant O&S costs are found to be Manpower, Replenishment Spares, and Initial Spares. For Manpower and Initial Spares, simplified models are discussed which give OASD visibility into the critical sensitivities of Army helicopter O&S costs. Of the parameters examined for the selected helicopters, O&S costs are most sensitive to the Mean Time Between Dynamic Component Removals ($MTBR_{DC}$). The report concludes with a discussion of bounding values of Army helicopter O&S cost that can be expected if extreme values of critical O&S cost driving parameters, including those assumed in the cost estimate's approach, are encountered in actual practice. Extreme values of O&S costs are found to be not more than approximately 36% above or below expected O&S costs because, under existing manning procedures, Manpower costs are relatively insensitive to design and logistic parameters (see Table 3).

The principal study conclusions and recommendations are summarized below and underlined in the text for ready reference:

1) Reliability Availability Maintainability/Logistics (RAMLOG) recorded Maintenance Man Hours per Flight Hour (MMH/FH) should not be the sole source of manpower estimates for the Visibility and Management of Operating and Support Costs (VAMOSC) program because they exclude indirect time expended by weapon system personnel (Chapter II).

2) Future Army data sources should include summaries of long-term reliability and maintainability trends for use in cost estimating (Chapter II).

3) The Army should resolve definitional inconsistencies in lower level manpower cost estimates so that BCE and IPCE values will be comparable at these levels (Chapter III, Section A).

4) Indirect manpower is a potential source of cost reduction within the Army provided that careful study is made of optimum indirect manpower levels for the size of the unit supported (Chapter III, Section A).

5) The historic data base for other than Aviation Systems Command (AVSCOM) costs incurred by helicopter units should be displayed in BCEs and IPCEs whenever these costs exceed 20% of the O&S category to which they contribute (Chapter III, Section B).

6) $MTBR_{DC}$ Levels achieved should be intensively reviewed to assure a desirable balance between funding for reliability achievement and expected O&S costs (Chapter III, Section B).

7) The Army should develop a resource allocation model to provide a first step toward optimizing vehicle availability by optimizing the choice of initial and replenishment spares purchased (Chapter III, Section C).

8) Weapon system cost estimates should include display of extreme values of O&S costs and the associated field experience values of major driving hardware design and logistic parameters including assumed values (Chapter VI).